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## GAS SENSOR

### Technical Field

5       The present invention relates to an optical gas sensor and particularly, to a non-dispersive infrared gas sensor.

### Background Technology

10      The principle of operation of a conventional optical gas sensor is as below.

Generally, the light intensity is decreased or increased by diffraction, reflection, refraction and absorption of light on the optical path. As incident light passes through the optical path, a gas on the optical path absorbs the light and the initial light intensity decreases.

15      When the gas concentration (J) is isotropic and distributed uniformly on the optical path, and infrared light passes through the optical path (L), the final light intensity (I) can be explained by the Beer-Lambert's law, which is the function of the gas absorption coefficient (k), path length (L) and initial light intensity ( $I_0$ ).

$$\text{That is, } I = I_0 \cdot e^{-KJL(x)} \quad \text{----- Equation (1)}$$

20      The Beer-Lambert's law is expressed as the above Equation (1). If the initial optical intensity ( $I_0$ ) and the absorption coefficient of a gas to be measured are constant, the final light intensity (I) is expressed as a function of the gas concentration (J) on the optical path and the path length (L).

If there is no gas to be measured in the above Equation (1), i.e., if  $J=0$ , the final

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light intensity becomes equal to the initial light intensity.

That is,  $I = I_0$  ----- Equation (2)

Hence, the difference of the light intensities between when there is no gas to be measured and when the gas concentration is  $J$  is obtained by Equation (3).

5        $\Delta I = I_0 \cdot (1 - e^{-KJL(x)})$  ----- Equation (3)

However, since the conventional infrared sensor outputs a voltage in proportion to the light intensity, the output of the sensor according to the existence or non-existence of a gas is expressed as Equation (4).

$$\Delta V = a \cdot \Delta I = a \cdot I_0 \cdot (1 - e^{-KJL(x)}) \text{ ----- Equation (4)}$$

10       In order to produce an optical gas sensor having a broad range of measurement from low concentration to high concentration, first, an optical cavity (or a gas chamber) having long light path ( $L$ ) should be provided; second, an infrared sensor of which the lowest limit of the detectable light intensity ( $I_{th}$ ) is sufficiently low should be used; or third, an infrared sensor having a saturation light intensity ( $I_{sat}$ ) which is relatively high and 15 slightly smaller than the initial light intensity ( $I_0$ ) radiated from an infrared source.

However, since the commercially available infrared detecting sensors (e.g., Thermopile IR sensor or Passive IR sensor) are not enough to satisfy all of the above conditions, an advantageous method of providing an optical cavity having long path is being required.

20       Various methods for extending the light path within a limited optical cavity have been suggested, one of which is U.S. Patent No. 5,341,214 titled "NDIR GAS ANALYSIS USING SPECTRAL RATIONING TECHNIQUE" invented by Jacob Y. Wong. As illustrated in Fig. 1, the invention intends to provide an optical path tube structure that causes multiple reflections that result in the average path length being even greater than the

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physical length of the optical waveguide. Also, it intends to increase the optical path by orienting the infrared emitted from the optical source to an arbitrary direction. However, an infrared gas sensor generally has a limited field of view for receiving incident light. Due to the limited field of view, the amount of light that substantially reaches the infrared 5 sensor for measurement is very small. Hence, the efficiency of the gas chamber is low, and the practicality lacks.

There is another method, which uses the White's Cell principle, disclosed in U.S. Patent No. 5,009,493 titled "MIRROR ARRANGEMENT FOR A BEAM PATH IN A MULTIPLE-REFLECTION MEASURING CELL." As illustrated in Fig. 2, a plurality 10 of focuses lie on the reflection surfaces of mirrors, so that incident light can be reflected a predetermined number of time by the three arranged reflective mirrors, and the length of optical path can extend to analyze even a small amount of gases on the optical path.

However, since this kind of system uses a laser as source of light, it is not appropriate to measure gases like CO<sub>2</sub>. Furthermore, it is difficult to be employed in a 15 small gas detector due to the long distance between the reflection surfaces.

Still another method was proposed by Christopher R. Sweet in U.S. Patent No. 5,488,227 titled "GAS ANALYZER", which constitutes a gas sensor by combination of a convex reflective mirror and a concave reflective mirror. In order to ensure an effectively long optical path, this method is characterized by installing a moving convex reflective 20 mirror in a gas cell, as illustrated in Fig. 3. The gas analyzer according to this method comprises a structure (12) for ensuring a certain space within a gas sensor and preventing internal pollution, a cover (13), a cylindrical optical reflective mirror (15), a step motor (16) for rotating the mirror, an infrared sensor (24), a rotational disc (21) having a plurality of filters and a step motor (23) for rotating the disc.

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However, since it is difficult to produce such a system and a step motor is needed for the rotation of the reflective mirror, it cannot be easily used in a small, portable and easy-to-use gas analyzer.

Still another method was disclosed in PCT/SE97/01366 (WO 98/09152) titled "GAS SENSOR" proposed by Martin. In order to provide a relatively long optical path in an optical cavity having a limited size, the method arranges three concave mirror surfaces as illustrated in Fig. 4. In other words, the gas sensor proposed by Martin comprises three elliptical concave surfaces, and it has an optical gas sensor cell structure, employing the White's cell concept of setting the focus of reflected light from each concave surface on or adjacent to the opposite reflection surface.

However, this gas sensor cell having three reflection surfaces is complex. Also, since the incident light, which is radiated from an optical source located on the surface of a main mirror (a mirror of one body) through an optical cavity, may have slight changes in its incident angle, it was difficult to determine the appropriate location of optical sensor.

The present invention relates to an optical gas sensor, more specifically to a non-dispersive infrared (NDIR) gas sensor.

There are two ways of measuring CO<sub>2</sub> concentration. One is NDIR system, and the other is solid electrolyte system as disclosed, for example, in "A carbon dioxide gas sensor based on solid electrolyte for air quality control" in *Sensors and Actuators B*. vol. 66, pp. 55-66, 2000 by K. Kaneyasu, *et al.*

Although the solid electrolyte sensor is less expensive than the NDIR sensor, the NDIR sensor is preferable in terms of long-term stability, high accuracy and low power consumption, etc. Also, the NDIR sensor has good selectivity and sensitivity since it employs the physical sensing principle that an objective gas absorbs infrared of a certain

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wavelength.

The optical characteristics of the NDIR sensor are as follows.

Generally, the light intensity is decreased or increased by diffraction, reflection, refraction and absorption of light on the optical path. As for an NDIR sensor, as the 5 incident light passes through the optical path, a gas on the optical path absorbs it and the initial light intensity becomes decreased.

When the gas concentration ( $J$ ) is isotropic and distributed uniformly on the optical path, and infrared light passes through the optical path ( $L$ ), the final light intensity ( $I$ ) can be explained by the Beer-Lambert's law, which is the function of the gas absorption 10 coefficient ( $k$ ), path length ( $L$ ) and initial light intensity ( $I_0$ ).

That is,  $I = I_0 \cdot e^{-kL(x)}$  ----- Equation (5)

The Beer-Lambert's law is expressed as the above Equation (5). If the initial optical intensity ( $I_0$ ) and the absorption coefficient ( $k$ ) of a gas to be measured are constant, the final light intensity ( $I$ ) is expressed as a function of the gas concentration ( $J$ ) on the 15 optical path and the path length ( $L$ ).

If there is no gas to be measured in the above Equation (5), i.e., if  $J=0$ , the final light intensity becomes equal to the initial light intensity.

That is,  $I = I_0$  ----- Equation (6)

Hence, the difference of the light intensities between when there is no gas to be 20 measured and when the gas concentration is  $J$  is obtained by Equation (7).

$\Delta I = I_0 \cdot (1 - e^{-kL(x)})$  ----- Equation (7)

However, since the conventional infrared sensor outputs a voltage in proportion to the light intensity, the output of the sensor according to the existence or non-existence of a gas is expressed as Equation (8).

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$$\Delta V = \alpha \cdot \Delta I = \alpha \cdot [I_0 \cdot (1 - e^{-kL(x)})] \text{ ----- Equation (8)}$$

where,  $\alpha$  is a proportional constant.

In order to produce an optical gas sensor having a broad range of measurement from low concentration to high concentration, first, an optical cavity (or a gas chamber) having long path (L) should be provided; second, an infrared sensor of which the lowest limit of the detectable light intensity ( $I_{th}$ ) is sufficiently low should be used; and third, an infrared sensor having a saturation light intensity ( $I_{sat}$ ) which is relatively high and slightly smaller than the initial light intensity ( $I_0$ ) radiated from an infrared source.

However, the commercially available infrared detecting sensors (e.g., Thermopile IR sensor or Passive IR sensor) are not enough to satisfy all of the above conditions, an advantageous method of providing an optical cavity having long path is required.

There are four kinds of optical cavities that have been applied to existing NDIR gas sensor systems.

First, as disclosed in U.S. Patent No. 5,444,249 of Jacob Y. Wong, which was issued on August 22, 1995, there is a square type or a cylindrical tube type having one infrared (IR) source and one light detector.

Next, as disclosed in U.S. Patent No. 6,067,840 invented by Mahesan Chelvayohan and issued on May 30, 2000 or as disclosed in the Article titled "An implementation of NDIR type CO<sub>2</sub> gas sample chamber and measuring hardware for capnograph system in consideration of time response characteristics" in *Journal of Korean Sensor Society*, vol. 5, no.5, pp. 279-285, 2001 by I.Y.Park, *et al.*, there is a type comprising one light detector and two IR optical sources for thermal aging compensation.

Third, what is disclosed in the Article titled "CO<sub>2</sub>/H<sub>2</sub>O Gas Sensor Using Tunable Fabry-Perot Filter with Wide Wavelength Range" in the IEEE International Conference on

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MEMS, pp. 319-322, 2003 by Makoto Noro, *et al.* is a type using a cylindrical tube optical cavity and applying a Fabry-Perot filter for selecting target gas wavelength.

Fourth, what is disclosed in PCT/SE97/01366 (WO 98/09152) titled "Gas Sensor" dated March 5, 1998 by Martin Hans, *et al.* is a type comprising three concave mirrors in 5 order to increase the light path within a chamber of a small volume.

Particularly, the method proposed by Martin relates to an optical gas sensor cell structure comprising three concave reflection surfaces and applying the White's cell concept of setting the focus of reflected light on or adjacent to the opposite reflection surface. This method has an advantage of simply providing a relatively long optical path 10 compared with other methods.

However, since the incident light, which is radiated from an optical source located on the surface of a main mirror (a mirror of one body) through an optical cavity, may have slight changes in its incident angle, it was difficult to determine the appropriate location of the optical sensor.

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#### Detailed Description of the Invention

The present invention has been conceived in order to resolve the aforesaid problems. The object of the present invention is to maximize the length of the optical 20 path and to provide an optical gas sensor having a broad measurement ranges with an optical cavity (or a gas chamber) structure that can be easily designed.

Also, the present invention provides a new optical cavity structure for a new optical gas sensor cell, and presents a new gas sensor based on the CO<sub>2</sub> concentration measurement experiment result of a sensor employing such an optical cavity.

For the aforesaid object, the optical gas sensor according to one aspect of the present invention comprises a gas chamber for housing a sample gas; a gas opening for injecting a sample gas into the gas chamber or for exhausting the sample gas from the gas chamber; an optical source for projecting infrared toward the sample gas; and an infrared 5 sensor for sensing the intensity of the infrared which has passed through the sample gas, wherein the wall of the gas chamber is composed of two opposing concave mirrors having different focusing distances but a common focus.

For the aforesaid object, the optical gas sensor according to another aspect of the present invention comprises a gas chamber for housing a sample gas; a gas opening for 10 injecting a sample gas into the gas chamber or for exhausting the sample gas from the gas chamber; an optical source for projecting infrared toward the sample gas; and an infrared sensor for sensing the intensity of the infrared which has passed through the sample gas, wherein the wall of the gas chamber is composed of two opposing concave mirrors having different focusing distances but a common focus, and the concave mirrors have curvatures 15 such that the incident light which is parallel to the axis of the concave mirror reflects on the surface of the concave mirror and passes through the focus of the concave mirror, and that the incident light, which has passed through the focus of the concave mirror reflects on the surface of the concave mirror and propagates parallel to the axis of the concave mirror.

The gas openings comprise a gas vent established at a certain wall of the gas 20 chamber and a plurality of gas diffusion halls disposed on the lower or upper support plate of the gas chamber.

The plurality of gas diffusion halls is covered by a gas filter.

The plurality of gas diffusion halls is preferably disposed on the axis of the incident light from the infrared sensor.

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The gas vent is advantageously curved downward or it can be equipped with a detachable cap.

The surface of the concave mirror is produced with gold plating or gold deposition.

5       The gas chamber contains a parabolic reflecting mirror integrally formed with the support plate of the gas chamber adjacent to the infrared optical source formed at the support plate.

The gas chamber has a light outlet for projecting at least a part of the infrared light from the infrared optical source on the support plate.

10       The infrared optical source can be disposed on the focus of the parabolic mirror.

The support plate of the gas chamber may comprise a height compensation structure for the inclination of the support plate due to the height of the infrared optical source.

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#### Brief Description of the Drawings

Figs. 1-4 illustrates an optical gas sensor of the prior art.

Fig. 5 shows an optical characteristic of a parabola-shaped mirror.

Fig. 6 shows an optical feature of an optical cavity system having two parabolic mirrors having a common focus.

20       Fig. 7 illustrates an optical path according to the differences in the focusing distances of two parabolic mirrors having a common focus.

Fig. 8 is a top plane view of an optical gas sensor according to one embodiment of the present invention.

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Fig. 9 is a sectional view of A-A' of the optical gas sensor illustrated in Fig. 8.

Fig. 10 is a sectional view of B-B' of the optical gas sensor illustrated in Fig. 8.

Fig. 11 is a sectional view of C-C' of the optical gas sensor illustrated in Fig. 8.

Fig. 12 is a perspective view of an optical gas sensor according to one  
5 embodiment of the present invention.

Fig. 13 is a top plane view of an optical gas sensor according to another  
embodiment of the present invention.

Fig. 14 is a sectional view of A-A' of the optical gas sensor illustrated in Fig. 13.

Fig. 15a shows a left half of an optical cavity according to one embodiment of the  
10 present invention.

Fig. 15b shows a right half of an optical cavity according to one embodiment of  
the present invention.

Fig. 15c shows the optical cavity assembled together according to the above  
embodiment.

15 Fig. 16 is an optical path generated from the optical cavity structure according to  
the above embodiment.

Fig. 17 illustrates the focusing effect of light, which is generated from the optical  
cavity structure according to the above embodiment.

20 Fig. 18 illustrates a receiving power on a light detector in the optical cavity  
structure according to the above embodiment of the present invention.

Fig. 19a shows a left half of an optical cavity according to another embodiment of  
the present invention.

Fig. 19b shows a right half of an optical cavity according to another embodiment  
of the present invention.

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Fig. 19c shows the optical cavity assembled together according to the above embodiment of the present invention.

Fig. 20 is an optical path generated from the optical cavity structure according to the above embodiment of the present invention.

5 Fig. 21 illustrates the focusing effect of light, which is generated from the optical cavity structure according to the above embodiment of the present invention.

Fig. 22 illustrates a receiving power on a light detector in the optical cavity structure according to another embodiment of the present invention.

10 Fig. 23 shows an NDIR gas sensor module according to one embodiment of the present invention.

Fig. 24 illustrates a feature of an output voltage according to CO<sub>2</sub> gas concentration at a room temperature to the NDIR gas module according to the above embodiment of the present invention.

15 Fig. 25 illustrates changes of the output voltage according to the pulse modulation time of the NDIR gas sensor module according to the above embodiment of the present invention.

Fig. 26 illustrates changes of the output voltage according to CO<sub>2</sub> gas concentration to the NDIR gas sensor module according to the above embodiment of the present invention.

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\* Terms of the essential constituents in the drawings \*

10, 15: gas chamber lower support plates

20: a first mirror

25: a first parabolic reflective mirror

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- 30: a second mirror
- 35: a second parabolic reflective mirror
- 40, 45: gas vents
- 50, 55: parabolic mirrors
- 5 60, 65: infrared sensors
- 70, 75: gas chamber upper plates
- 80, 85: optical outlets
- 90, 95: infrared lamps
- 100: a cap
- 10 110, 115: height compensation structures
- 120, 125: gas diffusion holes
- 130, 135: gas filters

15 Embodiments of the present invention will now be described with reference to the accompanying drawings.

Fig. 5 shows an optical characteristic of a parabolic reflective mirror.

As illustrated in Fig. 5, in case of a parabolic reflective mirror, the reflected light of an incident light which has entered parallel to the optical axis always passes through the focus of the reflective mirror, and the reflected light of an incident light which has passed 20 the focus of the mirror always propagates parallel to the optical axis.

The present invention uses these optical characteristics of a parabolic reflective mirror.

Fig. 6 shows an optical characteristic of an optical cavity system having two parabolic reflective mirrors having a common focus.

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The optical cavity system illustrated in Fig. 6 is arranged such that two parabolic reflective mirrors are opposed to each other to have a common focus, and two focal lengths ( $O_A\text{-}F$ ,  $O_B\text{-}F$ ) of the two parabolic reflective mirrors are not identical.

According to the position of light source, the optical cavity system is classified  
5 into a divergence system (Fig. 6a), in which an incident light is diverged in the optical cavity, and a convergence system (Fig. 6b), in which an incident light is converged in the optical cavity.

As illustrated in Fig. 6b, which satisfies condition  $O_A\text{-}F < O_B\text{-}F$ , if light enters from a concave surface (B) toward a focus F on the optical axis, the light passes through  
10 the focus and then it reflects from a concave surface (A) to be parallel to the optical axis. The reflected light repeats the process of being reflected again from the concave surface (B) until it converges into the optical axis and finally reaches the concave surface (A) or (B). Also, the light, which has converged into the optical axis, is reflected and recurred to the direction where it entered.

15 Divergence system also experiences the same process as the above convergence system, then the irradiated light, which has diverged from the optical axis, is located at the concave surface (A) or (B).

Fig. 7 illustrates an optical path according to the different focal distance of two parabolic reflective mirrors having a common focus.

20 As illustrated in Fig. 7(b), an optical cavity system wherein  $O_A\text{F} - O_B\text{F} > O_A'\text{F} - O_B'\text{F}$  has a feature that the optical path of optical cavity (C') is longer than that of optical path (C) since the number of optical reflection in the optical cavity (C') is more than that in the optical cavity (C) illustrated in Fig. 7(a).

As stated above, in the optical cavity system, wherein two parabolic reflective

mirrors are opposed to each other so that they have a common focus and the two focal distances ( $O_A$ -F,  $O_B$ -F) of two parabolic reflective mirrors are not identical, the length of the optical path can be controlled by changing the focal distance, and also the optical path can be controlled by changing the angle of the optical axis and the incident angle.

5       Also, since the two parabolic reflective mirrors have a common focus and different focal distance and the incident light converges into the optical axis, the location establishment of an infrared sensor becomes easy.

10      The optical gas sensor according to the present invention causes light reflections on the optical path between an optical source and an infrared sensor as many as possible by using the aforesaid optical characteristic of the optical cavity system, thereby lengthening the optical path in an optical cavity of a given size. Hereinafter, embodiments of the optical gas sensor according to the present invention will be described.

Fig. 8 is a top plane view of an optical gas sensor according to one embodiment of the present invention.

15      The optical gas sensor according to one embodiment of the present invention comprises a gas chamber, a gas vent (40), a parabolic mirror (50), an infrared sensor (60), an optical outlet (80), an infrared lamp (90), a height compensation structure (110), gas diffusion holes (120) and a gas filter (130), wherein said gas chamber comprises a gas chamber lower support plate (10), a first mirror (20), a second mirror (30) and a gas 20 chamber upper plate (70).

Upon reviewing the top plane view of the optical gas sensor illustrated in Fig. 8, the optical gas sensor comprises a gas chamber of a closed optical cavity that consists of a lower support plate (10), a gas chamber upper plate (70) and a chamber wall.

The gas chamber wall consists of a first mirror (20) and a second mirror (30),

wherein said first mirror (20) and said second mirror (30) have a common focus ( $F_1$ ), and they are configured as partial-circular-arcs having different curvature radii.

The reason for using two circular-arc-shaped mirrors is that in case of a circle, a focus is formed at the 1/2 point of the diameter, which works like a parabola. If light is 5 irradiated parallel to the optical axis, the path of reflected light is determined as the focus or adjacency of the focus. Thus, a certain portion of the circular-arc-shaped mirror shows a very similar or identical optical characteristic to that of a parabolic mirror.

An opening for irradiating infrared radiated from an infrared lamp (not shown) is formed in the first mirror (20), and a parabolic mirror (50) is formed on the gas chamber 10 lower support plate (10). The parabolic mirror (50) ensures straightforward radiation of light from the infrared lamp.

In addition, an optical outlet (80) for irradiating only partial infrared that is radiated from the infrared lamp is formed on the gas chamber lower support plate (10).

The infrared sensor (60) for detecting light irradiated from the infrared lamp is 15 disposed on the second mirror (30). A gas vent (40) for injecting a reference gas to identify the optical characteristic of the optical gas sensor and to perform initial correction is disposed at the position where the first mirror (20) meets the second mirror (30).

Upon reviewing the optical path of the optical gas sensor having aforesaid constitution, as illustrated in Fig. 8, infrared light, which has been introduced parallel to the 20 optical axis through the parabolic mirror (50), proceeds toward the second mirror (30). Subsequently, the infrared light, which has been reflected by the second mirror (30), passes through the common focus ( $F_1$ ) or adjacent to the common focus ( $F_1$ ) of the first mirror (20) and the second mirror (30) and is reflected by the first mirror (20). Finally, the converged infrared light reaches the infrared sensor (60) disposed on the second mirror

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(30).

Meanwhile, in order to minimize loss and scattered reflection of light when light is reflected from the wall of a gas chamber, the gas chamber can be made of a metal. In this event, scattered reflection can be reduced by mirror like finishing through surface 5 polishing inside of the metal.

At the time of producing a gas chamber made of a non-metallic material, loss of light can be minimized by coating a material layer having high reflectivity such as gold, nickel, silver and copper or twofold layer of gold/chrome on the chamber wall.

Following Table-1 shows reflectivity of various metals according to optical wavelength. It shows that gold and silver have at least 98% reflectivity at the optical wavelength of 800 nm or more, and aluminum and copper have at least about 94% reflectivity at the optical wavelength of 1  $\mu\text{m}$  or more. However, generally, silver, aluminum and copper, etc. are oxidized automatically and changed of its color if humidity is high at an ordinary temperature. Thus, in order to prevent aging and ensure long time 15 reliable reflective surface, it is preferable to process the chamber surface with gold.

(Table-1) Reflectivity of various metals according to optical wavelength

Optical wavelength	Optical reflectivity according to wavelength (%)			
	Au	Ag	Al	Cu
200nm	23	23	91	40
400nm	39	96	92	47
600nm	92	98	91	93
800nm	98	99	87	98
1 $\mu\text{m}$	99	99	94	98
2 $\mu\text{m}$	99	99	98	98
4 $\mu\text{m}$	99	99	98	99
5 $\mu\text{m}$	99	99	98	99

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Hence, for efficient reflection of infrared light, preferably, the reflection surfaces of the first mirror (20) and the second mirror (30) are coated or deposited with gold or gold/chrome.

Fig. 9 is a cut-away sectional view of A-A' of the optical gas sensor illustrated in Fig. 8. Upon reviewing Fig. 9, an optical vent (80) for introducing infrared light radiated from the infrared lamp (90) to the optical cavity is formed at the gas chamber lower support plate (10), and a parabolic mirror (50) for ensuring the straightness of incident light radiated from the infrared lamp is formed in a manner as being connected to the first mirror (20) and the gas chamber lower support plate (10).

The infrared lamp (90) is established at the lower part of the gas chamber lower support plate (10), and disposed on the focus of the parabolic mirror (50).

Fig. 10 is a cut-away sectional view of B-B' of the optical gas sensor illustrated in Fig. 8. Upon reviewing Fig. 10, a cap (100) coupled to the gas vent (40) for preventing the gas chamber from being polluted by dust, for example, is shown. The cap (100) can be separated from the gas vent (40).

A plurality of diffusion holes (120) for rapidly diffusing gas is formed on the gas chamber lower support plate (10). The gas diffusion holes (120) are covered with a gas filter (130) for selectively permeating only gas and avoiding diffusion of dust and humidity. Meanwhile, a height compensation structure (110) for compensating the height difference due to the infrared lamp (90) is formed under the gas chamber lower support plate (10).

Fig. 11 is a cut-away sectional view of C-C' of the optical gas sensor illustrated in Fig. 8. Upon reviewing Fig. 11, it can be understood that the plurality of diffusion holes (120) formed on the gas chamber lower support plate (10) are preferably formed on the same optical axis as the infrared sensor (60).

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Fig. 12 is a perspective view of the optical gas sensor reviewed in the above Figs. 8-11 according to one embodiment of the present invention.

Fig. 13 is a top plane view of an optical gas sensor according to another embodiment of the present invention. Fig. 14 is a sectional view of A-A' of the optical 5 gas sensor illustrated in Fig. 13.

The structure of the optical gas sensor illustrated in Fig. 13 is nearly the same as that of the optical gas sensor of the above Figs. 8-12 except that two mirrors forming a gas chamber wall are configured as parabolas instead of circular arcs.

In other words, the gas chamber wall of the optical gas sensor illustrated in Fig. 10 13 uses two opposing parabolic reflective mirrors having a common focus but different focal distance. Also, a gas vent (45) is curved in the direction of gravity to prevent internal pollution of the gas chamber.

Upon reviewing the operation principle of the optical gas sensor illustrated in Figs. 13 and 14, infrared light radiated through an infrared lamp (95) passes via an optical outlet 15 (85) and a parabolic mirror (55), and is entered into the gas chamber.

The incident light is entered toward the common focus of a first parabolic reflective mirror (25) and a second parabolic reflective mirror (35), reflected by the first and second parabolic reflective mirrors (25, 35) and converged. The light intensity is measured at an infrared sensor (65).

20 Although the present invention has been described with reference to particular embodiments, the description is only an example of the present invention. Various adaptations and combinations of features of the embodiments disclosed are within the scope of the invention as defined by the accompanied claims.

The object of the present invention is to produce an optical cavity for non-

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dispersive infrared gas sensor, comprising two concave mirrors which are opposed to each other, of which the section is a circular arc, of which the central point is located on the same axis, and which are optically closed except for an inlet for establishing an optical source, an outlet for establishing a light detector and gas inlet/outlets.

5       Also, the object of the present invention can be achieved by a non-dispersive infrared gas sensor comprising an optical source for irradiating infrared; a light detector for ultimately detecting light from the optical source; an optical cavity which is formed by two opposing concave mirrors of which the cross-section is a circular arc, of which the central point is located on the same axis, and which are optically closed except for the inlet for  
10      establishing an optical source and the outlet for establishing a light detector and gas in/outlets; an optical modulating part having a pulse modulation time of 200-600 ms and turn-off time of 2, 2.5 and 3 sec. for controlling the light irradiated from the optical source; and an amplification part for amplifying an electrical signal from the light detector.

15     Hereinafter, the present invention will be further explained with reference to the drawings illustrated in the embodiments of the present invention.

Basically, the optical cavity of the present invention is produced by circular arcs. The central point of the two circular arcs exists on the same axis.

Also, the embodiments of the present invention design the central point of each circular arc to be identical with the middle point of the straight line going from one circular  
20     arc to the other circular arc (the two centers of two circular arcs exist on the same straight line). The reason thereof is for irradiated light under a certain condition to be able to pass via a certain point on the same straight line (if the feature of a circular arc is applied identically with a parabola, the circular arcs are designed to pass via an identical focus). The reason for endowing this condition is, for example, to ensure the characteristic of a

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parabola also for a circular arc so that light entered into the mirror in parallel to the axis is converged into a focus. In other words, if the invention is designed as the above-proposed structure, the light irradiated horizontally to the axis is reflected on each mirror, heads for opposing surfaces and focuses at a certain point. As shown in the following  
5 result of trial experiments, it is because of the feature of parallel light being focused on the optical path.

Meanwhile, the above embodiments of the present invention are designed that two circular arcs have different radii, the central point of a circular arc having a longer radius exists outside of the circular arc having a shorter radius, and the central point of a circular  
10 arc having a shorter radius exists inside of the circular arc having a longer radius. In this case, it was experimentally confirmed that the optical path from an optical source to a light detector makes a proper number of circulations.

Under the condition in which all the above conditions are satisfied, in order to derive an optical cavity design for obtaining a light convergence effect and an optical  
15 cavity design for effectively increasing the optical path, optical simulations have been conducted as follows.

In the simulations, an infrared optical source having  $4.2 \mu\text{m}$  wavelength and input power of 0.66 watt, which is the consumption power under steady state operation, have been set. Also, the inside of the optical cavity has been coated with gold (Au) to simulate  
20 a mirror having approximately 97% reflectivity. This is because a gold thin film having a certain thickness has at least 97% reflectivity in the infrared range, particularly at the wavelength of  $1 \mu\text{m}$  or more. Also, incident light is parallel light that enters into the inlet hole vertically. Meanwhile, the shape, size and configuration of an active area, etc. of the light detector have been set to be identical with those of a commercially applicable infrared

sensor. Also, a program of TracePro® of Lambda Research Corporation has been used as an analysis tool for the simulations.

In a first simulation, an optical structure, which is illustrated in Figs. 15a, 15b and 15c, has been applied. The optical cavity of Fig. 15c is a combination of the left half of Fig. 15a and the right half of Fig. 15b. This is one example of a design for lowering manufacturing cost for an initial test and facilitating deposition of a gold thin film of a mirror. This combination is only an example, so another optical cavity having different combination still be possible. In other words, it is possible to produce an integral optical cavity through a mold, and deposit gold or coat with gold on the surface.

10        In the first simulation, the optical cavity has been designed that the optical path can be checked and that the focusing effect of light can be achieved to increase the amount of light detected by the optical detector while maintaining the size of the optical cavity to be small. In other words, as shown in Equation (8), in order to measure a very slight amount of gas, firstly, the length of optical path should be increased in the optical cavity, 15 secondly, an infrared sensor having small lowest light intensity ( $I_{th}$ ) capable of detecting infrared is used, or thirdly, an infrared sensor having saturation light intensity ( $I_{sat}$ ) that is relatively great but slightly smaller than the initial light intensity ( $I_0$ ) radiated from an infrared optical source can be used. In addition to the methods, there is a method of increasing the intensity of light reaching an infrared sensor through the focusing of light. 20        Hereinafter, the present invention will be explained with reference to the drawings.

Fig. 16 is an optical path generated from the optical cavity structure illustrated in Fig. 15c.

Fig. 16 illustrates the optical path of incident light, which provides useful information enabling to calculate the optical length in the optical cavity.

Fig. 17 illustrates the focusing effect of light, which is generated from the optical cavity structure illustrated in Fig. 15c.

Fig. 17 shows the feature of parallel light irradiated from optical source being condensed to a certain point. In other words, if light is irradiated from the optical source existing at a predetermined position to be parallel to the optical axis on which central points of the circular arcs are located, and reflected twice, it is focused adjacent to the infrared sensor located on the mirror opposite to the optical source, thereby increasing the output voltage of the infrared sensor.

Fig. 18 illustrates a receiving power on a light detector in the optical cavity structure illustrated in Fig. 15c.

In Fig. 18, the location of a light receiving point and the receiving power at each location are colored.

A second simulation has been designed to increase the optical path, which is necessary to detect a small amount of gas. The optical cavity structure illustrated in Figs. 19a, 19b, and 19c has been applied. The optical cavity of Fig. 19c has combined the left half of Fig. 19a and the right half of Fig. 19b. This combination is only an example, so another optical cavity having different combination still be possible. An integral type of an optical cavity is also possible.

In the second simulation, an optical cavity has been produced using circular arcs which meet the conditions of the optical cavity of the present invention, while applying the structure that if parallel light is irradiated adjacent to the central point (or to the central point) of two circular arcs, the two circular arcs cause the reflected light to reach a certain point near the central axis of the two circular arcs. However, when the number of reflection is increased the light receiving intensity may greatly differ between the

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simulation and embodiments due to decrease of light intensity in the real embodiments. Thus, on the purport of the simulation, in order to prevent the light receiving intensity from being decreased, the number of reflection has been limited to 5 times until the light reaches an infrared sensor. Also, in the above structure, in order to make light to reach near the center of the circular arcs, a light transmitter (an infrared source) and a light receiver (an infrared sensor) are positioned on the same circular arc. However, the above features are not a restriction of the present invention.

Fig. 20 is an optical path generated from the optical cavity structure illustrated in Fig. 19c.

Fig. 20 shows that the light radiated from the light transmitter, particularly the light discharged from the center of the transmitter, reaches the center of the light receiver, i.e., infrared sensor.

Fig. 21 illustrates the focusing effect of light, which is generated from the optical cavity structure illustrated in Fig. 19c.

Fig. 21 shows that a light bundle being greater than the size (e.g., radius of 2 mm) of the light transmitting part of optical source reaches the light receiver. The optical cavity structure having such configuration can be useful if it is applied to, for example, a multi gas sensor (e.g., sensor radius of 5 mm), which is a light receiver having larger radius than the optical source.

Fig. 22 illustrates a receiving power on a light detector in the optical cavity structure illustrated in Fig. 19c.

Fig. 22 shows that the energy of light per unit hour that reaches the light receiving part (round structure) of an infrared sensor is approximately 0.523 watt per hour. Upon comparing it with the ideal energy of 0.567 watt per hour that reaches the infrared sensor

without loss after 5 reflections, it is less as much as about 0.44 watt. The reason thereof is assumed because a part of light radiated from the light transmitter is diverged and reaches an area beyond the light receiving part of the infrared sensor.

Upon checking the optical path, focusing effect of light and receiving power of 5 each optical cavity in the above simulations using TracePro®, the following result can be obtained.

The path of light emitted from the central axis of the light transmitter can be confirmed for the entire length of the optical path. The optical cavity according to the present invention can achieve longer optical path than that of the prior art, and the focusing 10 effect of light can be additionally obtained. Also, if the optical source (output voltage: 0.66 watt) works under steady-state condition, it was ascertained that the light intensity reduced by reflectivity of the mirror reaches the light detector. Although the receiving power on the light detector is slightly smaller than the theoretically calculated value, considering that the whole light is not converged into the light detector, it is considered as 15 an appropriate result.

According to the above result of the simulations, particularly, the optical cavity of the first simulation, the following embodiment can be obtained.

The embodiment of the present invention employs two known components, i.e., an infrared optical source and a light detector. For an infrared optical source, for example, 20 the infrared optical source of Gilway technical lamp, which has a parabolic reflector for focusing of parallel light and radiates 1-5  $\mu\text{m}$  infrared, has been used. Also, the ZTP-315 GS thermocouple infrared detector of GE Thermometrics Technologies, which is used for the conventional heating, ventilating and air conditioner (HVAC) application for vehicles, has been employed, but due to the object of gas sensing of this study, the long wavelength

band-pass filter has been replaced to the CO<sub>2</sub> filter having 4.26  $\mu\text{m}$  central wavelength and 20 nm FWHM (Full Width Half Maximum).

Fig. 23 illustrates an NDIR gas sensor module according to the above embodiment of the present invention, which consists of three main parts. The first part is 5 an infrared modulating part wherein pulse duration time is 200-600 ms, and turn-off time is changed from 2 sec. to 3 sec. with 0.5 sec. interval. The second part is a new optical cavity structure suggested by the present invention. The third part is an amplifying circuit. In the embodiment, a secondary amplifying circuit having a reference voltage driver (LM 385) has been used.

10 Fig. 24 illustrates an output voltage versus CO<sub>2</sub> gas concentration at a room temperature for an NDIR gas module and a reference transmitter according to the above embodiment of the present invention. As shown in Fig. 24, the maximum output voltage of the new sensor module is about 4.75V at CO<sub>2</sub> gas concentration of 100 ppm. As the CO<sub>2</sub> gas concentration increases between 100-2,000 ppm, the maximum peak voltage of 15 the sensor module is reduced to 4.45V. The maximum difference of the peak voltage under the above CO<sub>2</sub> gas concentration variation between 100-2,000 ppm is 300mV.

Fig. 25 illustrates the output voltage difference according to the pulse modulation time when CO<sub>2</sub> gas concentration is consistent in the above embodiment of the present invention. The output voltage difference means the difference between the output voltage 20 in the turn-on state of the optical source and the output voltage in the turn-off state of the optical source. As the pulse modulation time increases, the output voltage difference also increases. However, if the pulse modulation time exceeds 500 ms, the output voltage difference begins to be saturated. Accordingly, the output voltage also becomes to have little difference between each other. Also, since the absorbed infrared intensity is high,

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discharge of the absorbed heat is not conducted completely and the lifetime of the optical source becomes shortened.

Fig. 26 illustrates changes of the output voltage according to the change of CO<sub>2</sub> gas concentration in the above embodiment of the present invention. It shows normalized 5 output signals of the NDIR sensor module when the CO<sub>2</sub> gas concentration increases between 100-2,000 ppm. The normal output signal exhibits the maximum change when the infrared pulse modulation time is 200 ms. As the modulation time increases between 300-500 ms, the normal output signal is considerably reduced.

Meanwhile, the maximum voltage difference is shown at 500 ms of pulse 10 duration time, but simultaneously the reference voltage slightly increases. The change of the output voltage becomes maximum at 200 ms of pulse duration time, and exhibits 18,000 times of amplification gain. At this time, the turn-off time of the infrared optical source is 3 sec.

Although the present invention has been described with reference to particular 15 embodiments of the NDIR gas sensor and the optical cavity, the description is only an example of the invention's application and should not be taken as limiting the scope of the present invention. Various adaptations and combinations of simulations and the embodiments disclosed are within the scope of the invention as defined by the appended claims.

20 For example, in order to obtain the parallel light of the present invention, another method of producing a parabolic type mirror in an optical cavity can be employed for production of a cost-effective optical cavity without the use of the product from Gilway technical lamp.

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### Industrial Applicability

As described above, according to the optical gas sensor according to the present invention, the length of the optical path, which has been projected from the infrared optical source, becomes considerably increased, and it is possible to measure gases from low concentration to high concentration. Also, various kinds of gases can be measured.

In addition, two concave mirrors have been used for the gas chamber wall, thereby achieving the effects of easy design and production of a gas sensor and reducing manufacturing cost.

10        The present invention has proposed a new gas sensor structure by improving the design of the optical cavity for the conventional NDIR gas sensor. The optical cavity structure of the present invention is very simple, which consists of two concave mirror surfaces, and the light bundle is focused on the light detector.

According to the present invention, a new optical cavity structure for an NDIR gas  
15      sensor having extended optical path and focusing feature of light can be obtained. By using the new optical cavity structure, a new sensor module can be obtained for air quality measuring system, HVAC system for vehicles, etc.